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The dielectric mirror 34 portion of the hybrid mirror preferably comprises alternating one-quarter wavelength layers of silicon nitride and silicon dioxide or other suitable dielectric materials. The alternating layer of the dielectric mirror 34 may be patterned either by etching of liftoff processes known to those skilled in the art. In an exemplary VCSEL embodiment in accordance with the present invention, a first layer 36 of the dielectric mirror 34 is preferably not a multiple of one-quarter wavelength. Rather the thickness of the first dielectric mirror layer 36 is preferably adjusted to compensate for the semiconductor anti-phase layer, ensuring that the dielectric mirror 34 is in-phase with the semiconductor mirror. <u>This first layer 36 shall hereinafter be referred to as a re-phase layer (36), as its function is to "re-phase" the effects of the anti-phase layer.</u>

C1

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An exemplary VCSEL designed for lasing operation at 0.845μm includes a hybrid semiconductor-dielectric mirror having twelve semiconductor periods, a $0.42\lambda_s$ anti-phase layer, a $0.55\lambda_s$ dielectric <u>re-phase</u> ~~phase matching~~ layer and seven dielectric mirror periods. In an exemplary embodiment the semiconductor mirror periods comprise alternating $0.25\lambda_s$ thick layers of $AL_{0.25}Ga_{0.75}As$ and AlAs with graded transition regions as is known in the art. The dielectric mirror periods comprise alternating $0.25\lambda_s$ thick layers of SiO2 and Si3N4. Beneath the dielectric mirror period is a dielectric <u>re-phase</u> ~~phase matching~~ layer. The combination of semiconductor and dielectric mirrors enable the placement of the anti-phased metal reflection at the optimal location within the upper hybrid mirror.

C2

Fig. 5 graphically depicts the index of refraction of an exemplary VCSEL as a function of axial distance from the cavity. The index of refraction alternates between 3 and 3.4 for the twelve semiconductor mirror periods, maintains the value of 3.4 for the anti-phase layer, increases to approximately 3.6 for the GaAs ohmic contact layer, decreases to a value of approximately 2 for the dielectric <u>re-phase</u> ~~spacer~~ layer and alternates between a value of 1.45 and 2 for the dielectric mirror periods.

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As shown in Fig. 5, a re-phase ~~spacer~~ layer 36 of the high-index material is preferably deposited upon the anti-phase layer, followed by low-high index pairs to correctly phase ~~phases~~ the surface reflection at the dielectric-to-air boundary. The high-index, silicon nitride has an index of approximately two while the low-index silicon dioxide material has an index of approximately 1.45. The dielectric re-phase ~~spacer~~ layer preferably compensates for the reflectivity of the semiconductor anti-phase layer to provide the proper phase between the dielectric mirror and the second semiconductor mirror. The thickness of re-phase ~~spacer~~ layer 36 is preferably slightly more than one-half wavelength, so that the sum of the re-phase ~~spacer~~ layer and the anti-phase layer is an integral number of half wavelengths. If the anti-phase layer is $0.41\lambda_s$ as in the previous example, then the ~~spacer~~ re-phase layer would be either $0.09\lambda_s$ or $0.59\lambda_s$. In addition, tuning layers to control the slope efficiency may be deposited on the surface or within the dielectric as disclosed in US Provisional Patent Application No. 60/125,916 filed March 24, 1999. The contents of the preceding application is hereby incorporated by reference.

C3

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As shown in Fig. 11, an alternate single mode VCSEL structure designed to control the modal overlap includes a hybrid semiconductor-dielectric mirror wherein the thickness of the dielectric re-phase ~~spacer~~ layer is spatially varied. The thickness of the dielectric re-phase ~~spacer~~ layer 72 is preferably varied on a sub-quarter wavelength basis to modify the resonant cavity wavelength λ_c. Lateral variation in the cavity wavelength in the axial direction results in an effective transverse index step. A shift in the resonant cavity wavelength may be used for single-mode index guiding. Index guiding of this form may be characterized by separating the wave equation into longitudinal and transverse solutions. The resulting transverse index change Δn is given by:

C4

$$\frac{\Delta n}{n_{eff}} = \frac{\Delta\lambda}{\lambda_c}$$

where n_{eff} is the effective (longitudinal mode weighted) index and λ_c is the resonant cavity wavelength. Shifts in cavity resonance on the order of about 1-4 nm may result in transverse index guiding for an 0.850μm VCSEL.

C4

Fig. 12 is an expanded cross-sectional view of the dielectric re-phase ~~spacer~~ layer 72 with varying lateral thickness shown in the cross-section of Fig. 11. The shift in cavity wavelength, $\Delta\lambda = \lambda_{c1} - \lambda_{c2}$, may be realized by forming a step in the thickness of the dielectric re-phase ~~spacer~~ layer 72. The step in the thickness of the dielectric re-phase ~~spacer~~ layer may be created by depositing part of the dielectric re-phase ~~spacer~~ layer, patterned either by liftoff or plasma etching, and then depositing the remainder of the dielectric re-phase ~~spacer~~ layer and ¼ λ_s mirror stack over the entire VCSEL cavity surface. The incorporation of the dielectric re-phase ~~spacer~~ layer with varying lateral thickness results in an index guide. Proper design of the index step creates a beam waist that significantly exceeds the diameter of the index guide, enabling control of the modal overlap with the anti-phase loss.